Sedki A, Hamza N, Zaffagnin T. Correlation Between Retrofitting Builiding Envelope and Thermal Improvement on Social Housing in Hot-Arid Climate. *In: Building Simulation and Optimization, Third IBPSA-England Conference*. 2016, Newcastle upon Tyne, UK: Newcastle University.

Link to Conference:

http://www.ibpsa.org/?page_id=797

Date deposited:

16/11/2016

CORRELATION BETWEEN RETROFITTING BUILDING ENVELOPE AND THERMAL IMPROVEMENT ON SOCIAL HOUSING IN HOT-ARID CLIMATE

ABSTRACT

This study examines the effectiveness of a combined strategy of retrofitting strategies using an agricultural residue (maize) as an external insulation material and natural ventilation behaviours to improve indoor thermal comfort in a residential building. A prototype for a social housing multi-storey building is selected in the the hot arid climate of Cairo, Egypt. Building performance simulation using IES<VE> (the produces version of 2013) is used to predict the effectiveness of adding an external organic insulation material on the building envelope. Behaviours of natural ventilation are then included to predict a naturalistic approach for indoor thermal management. The simulation was conducted in a typical floor apartment that facing the warmest south orientation. Results revealed that -comparing to the base case - an improvement of 5.5% happened in winter period when applying external insulation only, while this percentage reduced to be 4.4% when applying the combined strategy. Further, this combined strategy was effective in summer period as it has improved indoor comfort by 58.3% while an improvement of 10.2% occurred when applying external insulation only.

INTRODUCTION

As practices of building with high thermal mass mud walls disappeared by time in favour of contemporary construction materials that offer less time lag properties, it is essential to consider a combination of fabric insulation with a strategy for natural ventilation to improve indoor thermal conditions in hot arid climates (Roaf, 2001)

It is acknowledged that using external insulation, thermal mass (El-Hefnawi, 2000) with light colours external surfaces, shading devices (Gado, 2000 andAttia,2010) minimizing window to wall ratio (Hamza et al, 2001) and using nocturnal ventilation (Givoni,1998) will yield positive results in terms of thermal comfort and energy efficiency in various climatic zones in Egypt.

Technical interventions in this study focus on the building's envelope as the moderator between the indoor and outdoor environments. Accordingly, minimizing heat gain in a hot arid climate, through the building envelope is essential for reducing cooling energy demand. In a climate with large diurnal (day-night) temperature swings, this study looks at the impact of improving building fabric thermal insulation combined with natural ventilation behaviours to passively reduce cooling energy demand.

INSULATING MATERIALS CHARACTERISTIC PROPERTIES

Characteristics that influence insulant's performance are thermal conductivity, thermal resistance, transmittance, specific heat capacity and density. However, these criteria are extended in this study to include:

- The ecological aspect of this material (materials derived from organic or recycled sources and which do not use high levels of energy during production) and;
- Availability of raw materials for local production.
- Possibility of economic material production.
- Natural organic material (from animals or plants).

This study focuses on the application of natural organic materials to improve thermal comfort and energy efficiency in the case study buildings for the following reasons:

1. Natural insulation materials do not underperform when compared to manmade synthetic insulation. Further, they are renewable and sustainable materials.
2. The CO_2 footprint of natural organic insulation is considerably less than other forms of synthetic insulation materials.
3. The specific heat capacity, for a large number of natural fibre insulation materials, exceeds 2000 J/Kg.K, while, for mineral wool is only 800 J/Kg.K and for plastic insulations is 1400 J/Kg.K. when taking into account the high density of the majority of natural insulation materials, then, the thermal mass of natural insulants such as wood fiber, cellulose and hemp is higher than other forms of insulants with the same R- value.
4. There is a future possibility to produce natural insulants in Egypt as it has a large amount of

agricultural waste (El-Shimi, 2005). ThroughPublic-Private Partnership (PPP) and tax reliefs, the government can incentivise private construction firms to use agricultural residues to manufacture natural-based insulation materials.

previous studies te that maize stalks are considered the second highest agricultural residues in Egypt (El-Shimi, 2005; El-Mashad, 2003). Maize was selected as an insulation material for the case study. Table (1) below shows that the by-product of wheat constitutes the largest proportion of total wastes of agricultural products in Egypt, its application to this study was overlooked in the sense that there is no evidence - to the best of the researcher's knowledge - that it is produced as an insulation materials for buildings yet.

Table 1
Agricultural residues in Egypt (Hamdy, 1998)

CROPE	TOTAL WASTES (1000 TON)
Wheat	5998
Maize	3814
Sugar Cane	3634
Rice, Paddy	2724
Tomatoes	1441
Seed Cotton	835
Broad Beans, Dry	467
Sugar Beets	440
Potatoes	380
Wheat	5998

CASE STUDY TECHNICAL DETAILS BEFORE AND AFTER INTERVENTION

The case study is a six storey prototypical residential buildings for housing medium income families in Egypt. This section explains in details the building envelope in terms of thermal behaviour before and after adding the insulation. Each floor includes six apartments. Each apartment consists of a living room, two bedrooms, one kitchen and one bathroom. Figures 1 & 2 show the typical floor plan and the cross sections with the critical thermal points of the building envelope that will be presented before and after the interventions.

Figure 1 Case study floor plan before (above) and after intervention around external walls (below)

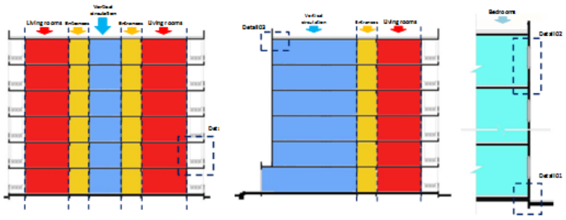
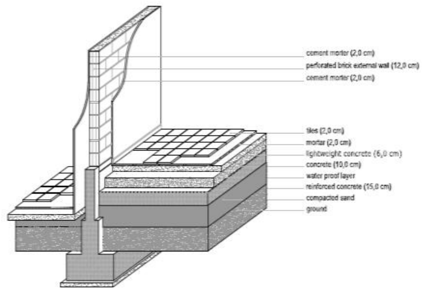
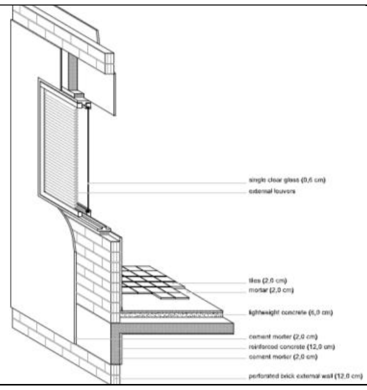


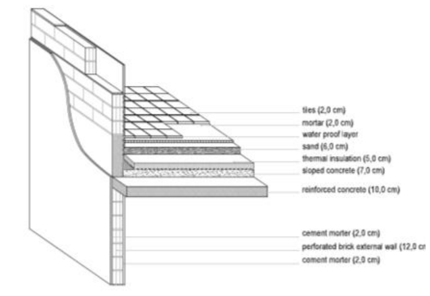
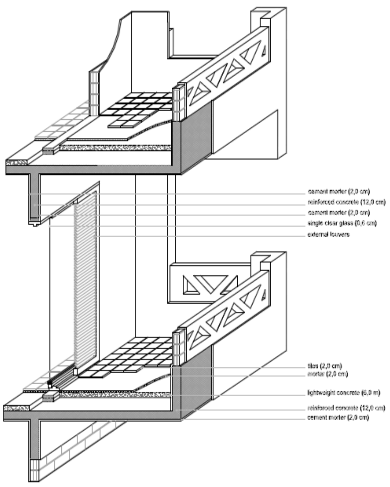
Figure 2 Case study sections showing the critical thermal points that are zoomed in table 2

Before intervention (Status-quo)

The following details (table 2) show the critical points in the building envelope before adding external insulation material (status-quo).

Table 2
Case study details before intervention (status-quo)

DETAIL	DRAWINGS
Detail 1 wall ground floor connection Detail	
Detail 2 window wall typical floor connection Detail (from outdoors)	

Detail 4 roof wall connection	
Detail 5 balcony wall connection Detail	

Tables 3 and 4 shows the thermal properties for the external wall and roof layers. Figures 3 and 4 show the predicted thermal behaviour of the wall and roof during the lowest recorded outdoor temperature in winter and highest recorded outdoor temperature in summer. According to IES<VE> data base for Cairo weather profile (the hourly average temperatures during 28 years), the lowest recorded average temperature was 7 ˚C, average external relative humidity was 87%and the highest average recorded temperature was 41.3 ˚C, average external relative humidity was 14%. Noticeably, the graphs show the poor thermal performance of the building envelope.

Table 3
Thermal properties of external wall layers

NO.	**THICKNESS**	**MATERIALS (IN TO OUT)**	**λ (W/MK)**	**R (M^2K/W)**	**U-VALUE (W/M^2K)**
		Thermal contact resistance		0.130	7.7
1	2	Plaster paint	0.25	0.008	125
2	20	cement render	1.40	0.014	71.4
3	120	Clay brick	0.60	0.182	5.5
4	20	cement render	1.40	0.014	71.4
5	2	Plaster paint	0.25	0.008	125
		Thermal contact resistance		0.040	25
	164	Whole component		0.396	2.53

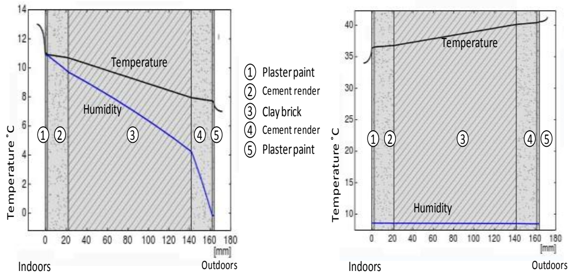


Figure 3 Thermal behaviour of the external wall during the lowest recorded temperature (on the left) and the highest recorded temperature (on the right)

Table 4
Thermal properties for roof layers

NO.	**THICKNESS**	**MATERIALS (IN TO OUT)**	**λ (W/MK)**	**R (M^2K/W)**	**U-VALUE (W/M^2K)**
		Thermal contact resistance		0.130	7.7
1	2	Plaster paint	0.25	0.008	125
2	20	cement mortar	1.40	0.014	71.4
3	100	Reinforced concrete	2.50	0.040	25
4	70	Sloped concrete	1.30	0.054	18.5
5	2	Water proof			
6		Insulation panels of maize fiber	0.036	1.7	0.58
7	60	sand	2.00	0.030	33.3

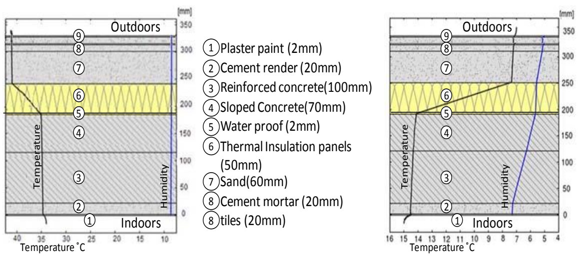


Figure 4Thermal behaviour of the roof during the lowest recorded temperature (on the left) and the highest recorded temperature (on the right)

After intervention

The following details in table 5 shows the critical points in the building envelop after adding the insulation material. Table 6 and figure 5 show the predicted thermal performance of the wall after adding external insulation.

Table 5

Case study details after intervention

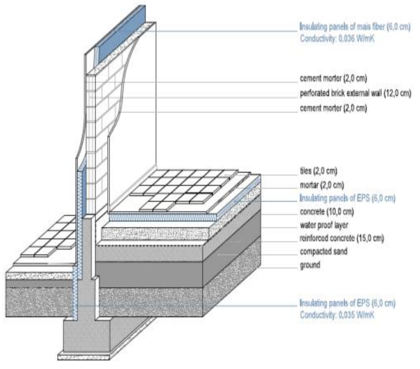
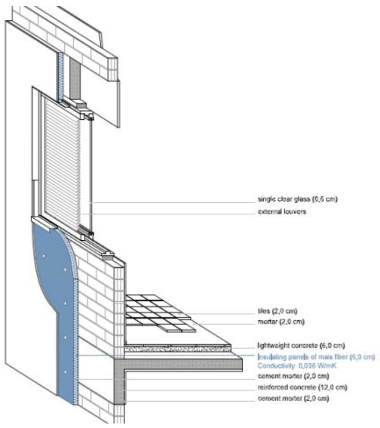
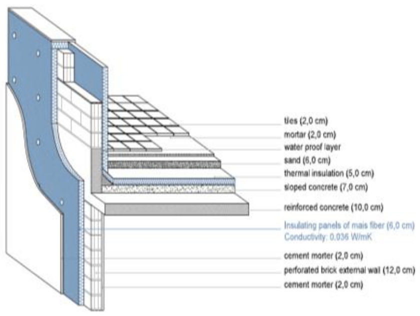
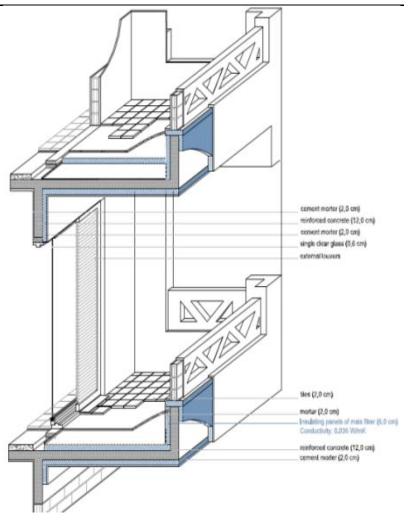
DETAIL	DRAWINGS
Detail 1 wall ground floor connection Detail	
Detail 3 window wall typical floor connection Detail (from outdoors)	
Detail 4 roof wall connection (external view)	
Detail 5 balcony wall connection Detail	

Table 6

External wall layer properties after adding insulation of maize fiber

NO.	THICKNESS	MATERIALS (IN TO OUT)	λ (W/MK)	R (M^2K/W)	U-VALUE (W/M^2K)
		Thermal contact resistance		0.130	7.7
1	2	Plaster paint	0.25	0.008	125
2	20	cement render	1.40	0.014	71.4
3	120	Clay brick	0.60	0.182	5.5
4	20	cement render	1.40	0.014	71.4
5	2	Plaster paint	0.25	0.008	125
6		Insulation panels of maize fiber	0.036	1.7	0.58
7	20	cement render	1.40	0.014	71.4
8	2	Plaster paint	0.25	0.008	125
		Thermal contact resistance		0.040	25
Total	164	Whole component		2.12	0.47

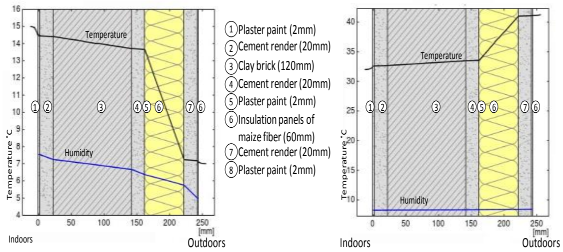


Figure 5 Thermal behaviour of the insulated external wall during the lowest recorded temperature (on the left) and the highest recorded temperature (on the right)

COMBINING INULSATION WITH NATURAL VENTILATION BEHAVIOURS

To examine the effectiveness of insulation retrofitting techniques with natural ventilation, natural ventilation behviours were applied. These behaviours were based on observational studies (Sedki, 2014). In winter, it was observed that occupants open the windows for short durations in the morning and afternoon when they come back from their work.This approximated to one hour for simulation reasons.

In summer the night purge ventilation was applied From 7:00 pm to 7:00 am. In consequence, the comparison made between the four scenarios shown in table (7).

Table 7

Case study simulation scenarios

SCENARIO NUMBER	DESCRIPTION
1	the base case (status-quo of the building with all windows are closed 24 hours)
2	the base case after adding external insulation of maize fiber and closing windows 24 hours
3	windows were opened from 8:00 to 9:00 and from 17:00 to 18:00 in winter and from 18:00 to 7:00 in summer without applying external insulation
4	the combination of scenarios (2) and (3)

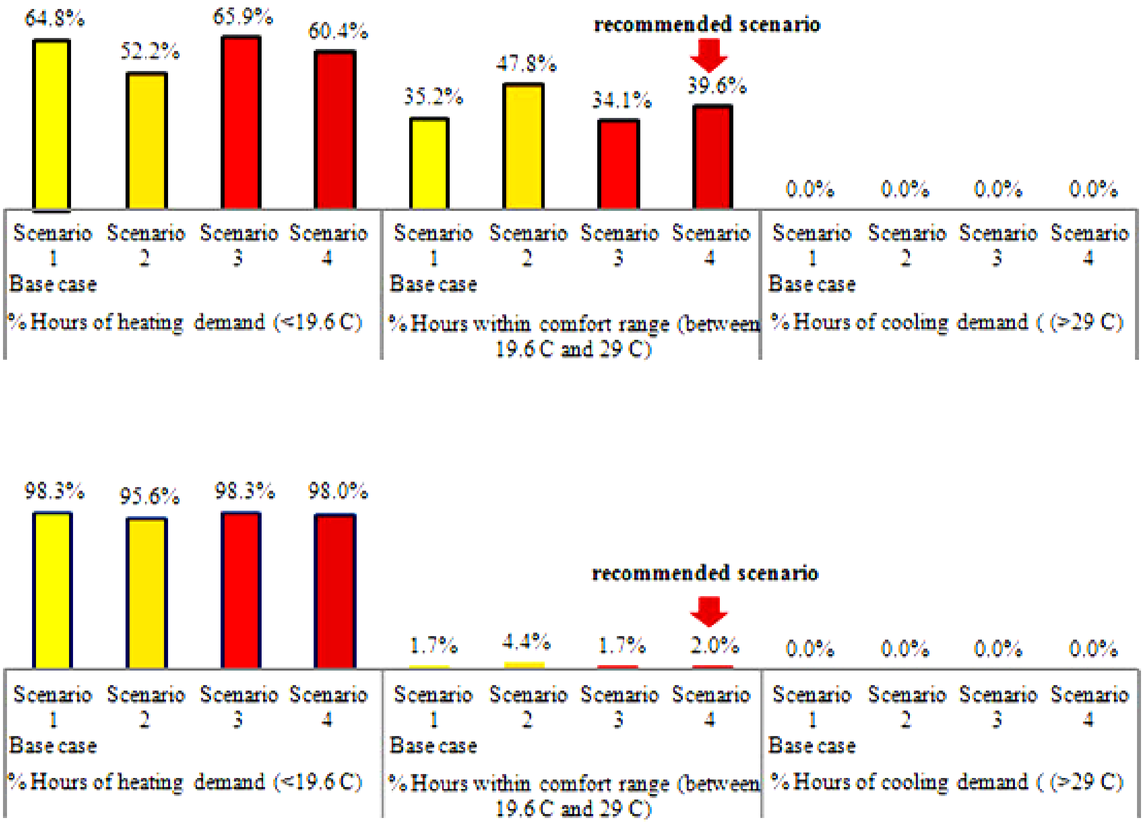


Figure 6 simulation results for the peak month of January (above) and conclusion of simulation results for the whole winter period (below)

Winter period

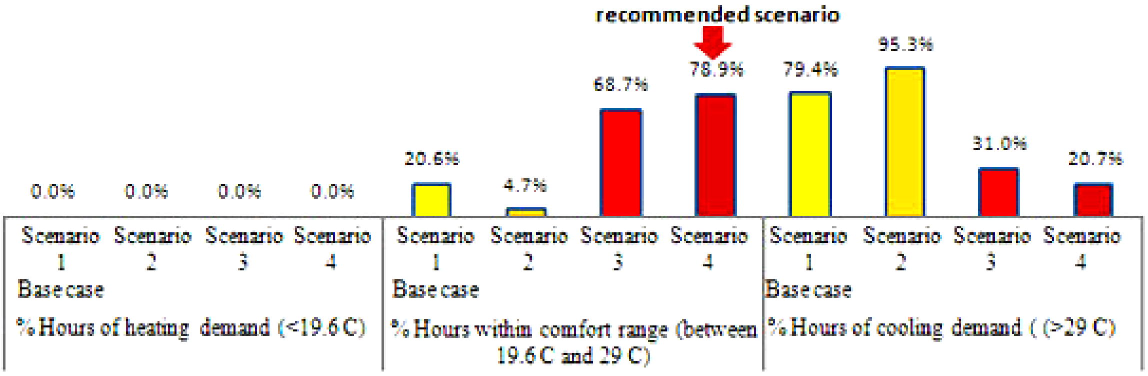
Homes in Cairo do not have central heating systems. Small electric heaters are used for heating spaces. This study looks at the possibility of passively increasing comfort in the winter period. the comparison was made among scenarios (1), (2), (3), and (4) shown in table 7.

In January, the peak heating dominated month in Cairo. Scenarios (1), (2), (3), and (4) achieved 1.7%, 4.4%, 1.7% and 2.0% respectively from total hours are within comfort range and 98.3%, 95.6%, 98.3% and 98.0% from total hours are of heating demand. Based on this comparison, there is no significant difference among all scenarios. Accordingly, none of them is effective during the month of January for the reference case under the climate condition of Cairo. Furthermore, scenario (2) achieved the highest range of comfort, however, it is not preferable because of indoor air quality reasons.

February, March, November, and December have got almost similar results of the month of January (Sedki, 2014).

From the above investigations for the whole period of winter months (the period of zero cooling demand in January, February, March, November and December) (Figure 6), among all presented scenarios, scenario (2) is the recommended one for indoor air quality reasons, however, it achieved the second highest range of comfort and it makes improvement by only 4.4% from the base case during all the total period of winter season. Consequently, this strategy is not much effective in winter season.

Summer period



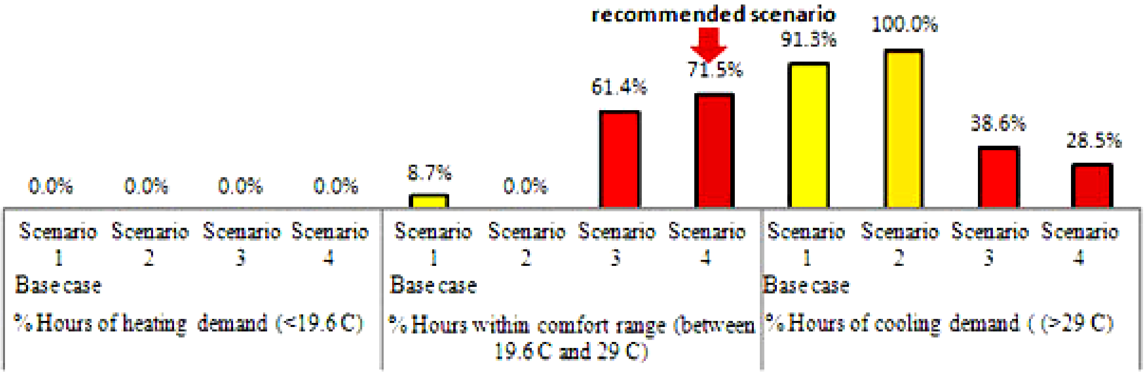


Figure 7 simulation results for the peak month of July (above) and conclusion of simulation results for the whole summer period (below)

Homes in Cairo do not have central cooling systems. Rich people put air conditioning units for cooling spaces. The study seeks to passively increasing comfort for the low income class people who live in the case study buildings in summer period. the comparison was made among scenarios (1), (2), (3), and (4) shown in table 7.

In July (figure 7), this is one of the peak months of cooling demand in Cairo. Scenarios (1), (2), (3), and (4) achieved 8.7%, 0.0%, 61.4% and 71.5% from total hours are within comfort range and 91.3%, 100.0%, 38.6% and 28.5%from total hours are of cooling demand. Based on this comparison, thermal comfort was significantly improved comparing to the base case when combining the external insulation with an appropriate occupant behaviour of night purge ventilation in this month.

June, August, and September, have got almost parallel results of the month of July (Sedki, 2014).

From the above investigations for the whole period of summer months (the period of zero heating demand in June, July, August, and September) (Figure 7), the application of external insulation combined with an appropriate occupant behaviour of night purge ventilation on the case study (scenario 4) made an improvement in indoor thermal comfort by 58.3% from the base case during all the total period of summer season. Further, by comparing scenario 3 and 4, it shows that applying external insulation only made a slight improvement in indoor thermal comfort during the whole summer period, this illuminates the importance to combine it with occupant behavioural natural ventilation strategy.

Noticeably, in scenario 2 when apply external insulation on the case study with closed windows 24 hours, it gave negative effect in comfort level probably because it decreases heat loss by traping the internal heat gains inside the spaces and stop the heat exchange process through building envelop.

CONCLUSIONS

This study examined the effectiveness of combining external insulation retrofitting technique made of a local organic insulation material with natural ventilation strategies on indoor thermal comfort. Natural ventilation scenario was applied according to occupants behaviour in winter as they opening windows in the morning and afternoon. In summer, the night purge ventilation was applied.

In winter, Building performacne simulation results indicate that applying insulation on the base case scenario (windows closed 24 hours) achieved the highest improvement in comfort by 2.7% comparing to the base case, however, it is not preferable as it leads to poor indoor air quality.

The combined strategy of external insulation and ventilation achieved the second highest range of comfort hours passively and is better for indoor air quality. However, with minor improvements by only 0.3% from the base case during the winter season.

For the summer months, the application of external insulation combined with night purge ventilation on the case study made an improvement in indoor thermal comfort by 58.3% from the base case. Further, external insulation only made a minor improvement, thus, the combined strategy is highly recommended in summer season.

REFERENCES

Attia, S. 2010. Zero energy retrofit: Case study of a chalet in Ain-Sukhna, Egypt. In Proceedings of the Solar (pp. 17-22).

DIN 4108-7, 2001. "Thermal insulation and energy economy of buildings - Part 7: Airtightness of building, requirements, recommendations and examples for planning and performance", Deutsches Institut fur Normung.

ECP 306 2008. Egyptian code for improving energy efficiency in buildings – part one: residential buildings. Housing and building research center, ministry of housing and urban development, Egypt.

El-Hefnawi, A. I. K. 2000. Climatic design for low-cost housing in Egypt "Case of the Youth Housing Project in El-Obour City". AEE" Architecture, Energy & Environment"-Tools for climatic design-Advanced International Training Programme. Lund University, Lund, Sweden.

El-Shimi S. 2005. Design and Cost Analysis of Agriculture Wastes Recycling Alternatives for Sinbo Village, Gharbiya Governorate. Ministry of water, resources and irrigation, Egypt, pp.6-15.

El-Mashad, H. M., van Loon, W. K., Zeeman, G., Bot, G. P., & Lettinga, G. 2003. Reuse potential of agricultural wastes in semi-arid regions: Egypt as a case study. Reviews in Environmental Science and Biotechnology, 2(1), 53-66.

Gado, T. 2000. A parametric analysis of thermal comfort and cooling in walk-up housing blocks in the Arab Republic of Egypt. MSc., Welsh School of Architecture, University of Wales, Cardiff.

Givoni, B. 1998. Climate considerations in building and urban design. John Wiley & Sons.

Hamdy, Y. A. 1998. The current situation of Egyptian agricultural wastes. In The Proceedings of Anaerobic Treatment of Solid Wastes Workshop (Vol. 4, pp. 1-5).

Hamza N, Dudek S, Elkadi H. 2001. Impacts of Facade Retrofitting with a Hybrid Climatically Interactive Building Skin on Energy Consumption in Hot Arid Areas. *In: International Conference on Building Envelope Systems and Technologies (ICBEST).* 2001, Ottowa, Canada.

Ogoli, D. M. 2003. Predicting indoor temperatures in closed buildings with high thermal mass. Energy and Buildings, 35(9), 851-862.

Okba, E. M. 2005. Building envelope design as a passive cooling technique. In Proceedings from the.

Pfundstein, M., Gellert, R., Spitzner, M., & Rudolphi, A. 2007. Insulating materials: principles, materials, applications. Walter de Gruyter.

Sedki A, Hamza N, Zaffagnini T. 2013. Field Measurements to Validate Simulated Indoor Air Temperature Predictions: A case study of a residential building in a hot arid climate. IBPSA Egypt, 1st conference about Building Simulation Contributions in Built Environment in Egypt, Cairo, Egypt 23 - 24 June 2013, pp. 338 – 347.

Sedki A, Hamza N, Zaffagnini T. 2014. Improving Indoor thermal comfort in residential buildings in hot arid climates through the combination of natural ventilation and insulation retrofitting techniques – case study: Existing social housing stocks in Greater Cairo. PhD.

Smith, P. F. 2004. Eco-refurbishment: a guide to saving and producing energy in the home. Routledge, pp. 7-25.

Straube, J. 2006. Thermal Control in Buildings. Building Science Digest 011, Building Science Press, pp. 1-12.

Thomas, R. (Ed.). 2006. Environmental design: an introduction for architects and engineers. Taylor & Francis. pp. 7-145.

Waters, J. R. 2005. Energy conservation in Buildings: A Guide to part L of the Building Regulations. John Wiley & Sons.